ATMOSPHERIC MODELING IN THE SYNTHETIC THEATER OF WAR (STOW 97)
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ABSTRACT

The Synthetic Theater of War is the major application of a Defense Advanced Research Projects Agency thrust in Advanced Distributed Simulation (ADS). The STOW Program focuses on an Advanced Concept Technology Demonstration termed STOW 97 sponsored by DARPA with the United States Atlantic Command. To support ADS applications up to the Joint Task Force level, STOW seeks to develop and demonstrate technologies enabling the integration of war-fighting through virtual and constructive simulations from geographically distributed locations in a common synthetic battlespace.

The U.S. Army Topographic Engineering Center is developing, under Contract to Lockheed Martin, a synthetic environment, Dynamic Virtual Worlds, which will enhance the virtual battlefield with real world environmental effects using atmospheric models developed by the Army Research Laboratory that vary temporally and spatially. This paper summarizes the atmospheric effects that are being demonstrated in the Dynamic Virtual Worlds program within STOW 97.

1.0 Introduction

Weather has always played a decisive role in warfare. Literature, movies, and historical accounts of battles depict the struggles of the infantryman trudging through the sloppy mud of the jungle, the snowy cold of the North, or the searing heat of the desert. The eventual winner of the battle was almost always the individual or battle group who could better withstand the elements of weather and turn those elements to their benefit. A frequently heard statement is, “The weather affects the enemy just the same as it affects us, so it is not a factor to the outcome.” This has been a false assumption for as long as history has recorded armed conflict. An example is Napoleon’s wintertime invasion of Russia. And it is certainly improper to assume such a posture in modern or future warfare.

The Synthetic Theater of War (STOW) is the major application of a Defense Advanced Research Projects Agency (DARPA) thrust in Advanced Distributed Simulation (ADS). The STOW Program focuses on an Advanced Concept Technology Demonstration termed STOW 97 sponsored by DARPA with the United States Atlantic Command (USACOM). The successful implementation of STOW 97 technologies in November 1997 with the United Endeavor 98-1 Exercise will mark the full operational capacity of the USACOM Joint Training, Analysis and Simulation Center. To support ADS applications up to the Joint Task Force level, STOW seeks to develop and demonstrate technologies enabling the integration of war-fighting through virtual and constructive simulations from geographically distributed locations in a common synthetic battlespace.

Serving as DARPA Agent, the U.S. Army Topographic Engineering Center has awarded research and development contracts to develop advanced technologies in four areas: 1) physics-based environmental effects under the Dynamic Virtual Worlds (DVW); 2) dynamic terrain and multi-state objects under the Dynamic Terrain and Objects; 3) atmospheric and ocean data services under the Total Atmosphere and Ocean Server (TAOS); and 4) next generation terrain data base representations under the Improved Computer Generated Forces Terrain Data Base. This paper will only discuss (1) above.

2.0 Dynamic Virtual Worlds

Lockheed Martin Advanced Distributed Simulation (LADS) of Bellevue, Washington and Cambridge, Massachusetts is performing the integration of environmental feature models into ModSAF (Modular Semi-Automated Forces), and complementary visualization capabilities known as ModStealth. ModSAF was selected as the computer generated forces system because of its open architecture, wide use, and ready availability. The visualization of environmental effects is being demonstrated in the new OpenScene “stealth” system. The DVW (Turner, 1996) program enhances the virtual battlefield with real world environmental effects that vary temporally and spatially. Examples of effects currently modeled include the variation of illumination with time-of-day; obscuration of the battlefield from artillery-generated dust, vehicle dust, smoke from burning tanks, and tactical offensive and defensive smoke sources; the effects of boundary layer aerosols (fog, haze, rain, and snow); signal and illumination flares; hydrology; and the effects of dynamic environments on mobility. All of the atmospheric models currently being used by DVW are contained in the Electro-Optical Atmospheric Effects Library (EOSAEL) (Shirkey, et al, 1987). EOSAEL has been constructed by the Army Research Laboratory’s, Information Sciences and Technology’s, Battlefield Environment Division; EOSAEL has been evolutionary, with its inception in 1979 and four revisions since then. A new revision is currently available through the Test and Evaluation Community Network Bulletin Board System (TECNET).

2.1 The Electro-Optical Systems Effects Library

EOSAEL provides an integrated methodology to investigate atmospheric effects on radiation passing through the fog-of-war. It is a state-of-the-art computer library comprised of fast-running theoretical, semi-empirical, and empirical computer programs that mathematically describe various aspects of electromagnetic propagation and battlefield environments. The models are more engineering oriented than first principles. The philosophy is to include modules that give reasonably accurate results with the minimum in computer time for conditions that may be expected on the battlefield.

The modules contained in EOSAEL are organized into eight generic atmospheric effects areas: gases, natural aerosols, battlefield aerosols, radiative transfer, laser propagation, and target acquisition, system performance and support. Details of the physics embodied in these modules and their usage may be found in the various EOSAEL volumes (EOSAEL 87) and at the internet site "http://www. eosael.tom".

2.2 ModSAF Weather Editor

In order to aid in the setting up and running of DVW coupled with the underlying EOSAEL, a weather editor has been constructed by LADS, appropriately named the ModSAF weather editor. The ModSAF weather editor supports uniform, homogeneous, atmospheric parameter settings. A widget controlled graphical user interface supports setting time-of-day, temperature, wind speed and direction, precipitation type and rate, extinction type and amount, cloud cover, barometric pressure and dewpoint. The weather editor establishes uniform conditions for the entire data base. Although not representative of a 3-D spatially variant natural environment, the weather editor does provide a robust tool for localized model testing and general scenario simulation. For example, an operator can modify the data base's wind speed and direction to analyze the change in a smoke plume's dispersion down wind. Likewise, an operator can set the date and time-of-day to analyze a scenario during a rising or setting sun. The atmospheric settings are also used to feed the environmental models discussed below.

2.3 Natural Illumination

Many simulation systems today operate in a static, full daylight environment. The STOW program can compute dynamic time-of-day capability to provide continuous changes to the ambient lighting contributions from solar, lunar, and sky background sources. The EOSAEL ILUMA model (Duncan, et al, 1987) describes natural illumination under realistic atmospheric conditions that include clear skies, partly cloudy and overcast conditions, precipitation and fog . The total illumination is computed as the sum of the contributions from the sun, the moon and the background sky. At night, scattered light from nearby cities (or other sources of artificial light) can significantly enhance the horizontal illumination at a given location; shadows cast by natural or man-made objects may also significantly reduce the available illumination. Neither of these problems is addressed in the current model because of the detailed, site-specific, physical modeling required for their treatments.

Computer codes based on extinction or single scattering have been widely used to predict atmospheric transmittance (Kneizys, et al, 1983). Light propagation in the atmosphere, however, is a multiple scattering process in which radiation scattered by one element can be scattered again by another element. Numerous large computer codes have been developed for performing exacting multiple scattering radiation transfer calculations. Because of the memory requirements and execution time limitations, these codes are not practical for real-time battlefield applications. In addition, to develop a computer code that requires inputs that cannot reasonably be expected to be available is not practical. Cloud observations, especially under tactical situations, usually provide the types and amounts of high-, middle-, and low-level clouds. Since these observations are taken by a human observer, no information above an overcast layer is obtained. Also, note that this information does not include cloud thickness, types of aerosols in the cloud, and aerosol size distribution -- quantities that are desirable for detailed radiation transfer calculations.

ILUMA employs Shapiro's three-layer atmosphere model, which uses the doubling method for determining solar insolation at the surface. Details of Shapiro's methodology may be found in Shapiro (1982).

2.3.1 Calculation of Illumination

Conceptually the calculation is straightforward, given the formulas developed in (Duncan, et al, 1987). Beginning with location and time, one would calculate the zenith angles of the sun and the moon. The fractional transmittances would be computed and multiplied by known values of the **illuminance** at the top of the atmosphere to obtain the surface values. Because of the approximate nature of the transmission and reflection functions (and hence the fractional transmittances), an alternate procedure was adopted. The **illuminance** were calculated from empirical data for clear sky conditions (van Bochove, 1982). These values were then multiplied by the ratio of the fractional transmittance for the specified weather condition and the fractional transmittance for clear conditions.

When the sun and moon are well below the horizon, illumination is significantly higher than would be predicted from these two sources. Sources for this additional illumination, called the background sky illumination, include starlight and airglow (RCA, 1974). Published values for this contribution to illumination vary from 0.00007 to 0.00025 fc. A mean value of 0.00015 fc has been included in the current model.

The model has been designed to accept data that are generally available through routine weather observations. These data include the types and amounts of high-, middle-, and low-level clouds and the occurrence, or nonoccurrence, of fog or precipitation. The resultant three-layer radiative transfer model responds to inputs of the types and amounts of such clouds. Admittedly such a simplified approach results in some error in the computation of the transmission of visible light through the atmosphere. However, more detailed calculations that would probably provide more accuracy typically require input data that are not routinely available.

The comparisons (Duncan, et al, 1987) show that the model predicts reasonable values when compared to the field measurements available. The model has a general tendency to slightly under predict. Although the exact cause for this tendency has not been determined, it may be largely a result of contributions to measured illumination from artificial light sources (nearby cities).

ILUMA thus allows the STOW simulation exercises to operate around the clock by providing continuous characterizations of natural illumination from sunrise to sunset and from full daylight to total darkness.

2.3.2 Inherent Contrast

Natural illumination in STOW simulations prompted the extension of ModSAF target detection models to leverage variable lighting conditions.

Inherent contrast describes the color difference between a vehicle and its background. Developed by the U.S. Army Night Vision Laboratory (Decker, 1988), the contrast model provides a measure of a target's maximum potential visibility based on four factors: 1) target type, 2) target background, 3) illumination source for the target, and 4) spectral waveband in which the target is being sensed.

Parameters for target type include woodland and desert, Army camouflage paint, Army tan paint, fatigue uniforms, dark brown paint, light brown paint, or 3 types of foreign paint schemes. Background type is broken into the following categories: sandy soil, gravel roads, concrete, asphalt, rocky soil, map green, map light green, top soil and sky. The illumination source can consist of either sun, moon or stars, and sensor types may include daylight vision optics or night vision optics. These parameters are fed through contrast model lookup tables to determine the target's inherent contrast.

2.4 Atmospheric Transmission

The representation of haze, dust, rain and snow within ModSAF and OpenScene provide a powerful simulation mechanism to degrade once environmentally static sensor simulations. STOW currently supports simulation of these atmospheric phenomenon in the context of atmospheric transmission.

Atmospheric transmission, or transmissivity, describes the visibility effects of boundary-level aerosols (haze, dust) and precipitation. Beer's law is used to calculate the transmittance:

$$T_\lambda(R) = \mathbf{e}^{(-K_\lambda R)}$$

where

$T_\lambda(R)$ = the transmittance at range R and wavelength λ
K_λ = the extinction coefficient at λ.

Transmissivity is determined via the use of three models: 1) the LOWTRN model, which was developed by the U.S. Air Force's Geophysics Laboratory and incorporated into EOSAEL; 2) the EOSAEL XSCALE model (for transmissivity due to snow); and 3) a model used to calculate the transmissivity of a dust storm.

In ModSAF, the output of the LOWTRN, XSCALE, and the dust storm model is stored in a series of lookup tables as extinction coefficients. These extinction coefficients are used to provide appropriate visualization cues in OpenScene and to degrade sensor and target detection in ModSAF.

The calculations of transmission within DVW for haze, fog, and rain use the formulation found in the EOSAEL version of LOWTRAN (LOWTRN) (Pierluissi and Maragoudakis, 1987). The EOSAEL version differs only in that some coding not relevant to Army usage was deleted.

There are two options for producing visible fog, haze or rain in DVW which are: using LOWTRAN and using inputs from the TAOS program. The ModSAF and OpenScene applications are run in slightly different manners: this is due to the fact that ModSAF needs data bases from LOWTRAN whereas OpenScene can use LOWTRAN on the fly (real-time).

2.4.1 LOWTRAN usage in DVW

When LOWTRAN is employed the atmosphere is considered to be horizontally homogeneous - vertical stratification that may be existent in LOWTRAN is used, but due to the nature of Army warfare (close to the ground) this vertical stratification is not frequently invoked. The following discussion is taken from the original LOWTRAN 5 and 6 reports (Kneizys, et al, 1980 and 1983). The aerosols that are currently implemented in DVW (others could be added if so desired) from LOWTRAN are rural (for haze), two types of fog (advection and radiation), and rain at six different rates.

2.4.1.1 Rural aerosol. Haze (10-, 5-, and 2-km meteorological ranges) can be represented by the rural aerosol within the boundary layer (O - 2 km). Within the boundary layer the shape of the aerosol size distribution and the composition of the model at the surface is assumed to be invariant with altitude. The rural model is intended to represent the aerosol condition one finds in continental areas which are not directly influenced by urban and/or industrial aerosol sources. The rural aerosols are assumed to be composed of a mixture of 70 percent water-soluble substance and 30 percent dust-like aerosols. The rural size distribution is parameterized as the sum of two log-normal size distributions.

2.4.1.2 Fog models. When the air becomes nearly saturated with water vapor, fog can form. Saturation of the air can occur as the result of two different processes; the mixing of air masses with different temperatures and/or humidities (advection fogs), or by cooling of the air to the point where its temperature approaches the dew-point temperature (radiation fogs). When using a fog model it is assumed that the visibility is less than 200 m for thick fogs and the extinction will be virtually independent of wavelength. For these conditions the advection fog model should be used. For light to moderate fogs, the visibility will be 200 to 1000 m and the radiation fog model should be used. For thin fog conditions where the visibility may be 1 to 2 km, the 99 percent relative humidity aerosol models may represent the wavelength dependence of the atmospheric extinction as well as any of the fog models. A modified gamma size distribution was used to construct these fog models (Shettle and Fenn, 1979).

2.4.1.3 Rain model. The Marshall-Palmer (MP) raindrop size distribution is used because the two main components are rain rate and drop diameter, and the MP raindrop size distribution is widely accepted in the research community. Note that the extinction due to rain is independent of wavelength.

In passing it should be noted that MODTRAN (Berk, et al, 1989) is not employed as the wavelengths used here are primarily in the visible and current sensors modeled are not narrow band. If the visualization were to be in the IR or narrow band sensors were to be used, then MODTRAN would have to be employed to represent the atmospheric transmission more accurately.

2.4.2 TAOS usage in DVW

When TAOS 4-D gridded data is available, the required information is taken from the 3-D distributed weather grid sources such as observations or weather models. In this case horizontal and vertical 3-D inhomogeneities are allowed the extinction coefficients are more closely aligned with real weather, rather than modeled weather. When run in this mode the information passed is of three types: 1) extinction type (rural, etc.) and precipitation type (rain, etc.) ; 2) meteorological range; and 3) the extinction coefficient.

2.4.3 Attenuation Through Falling Snow

XSCALE (Fiegel, 1994) calculates the transmittance through the naturally occurring aerosols of haze, fog, rain, snow, and ice fog. XSCALE models the wavelength dependence of transmittance on these aerosols for line-of-sight (LOS) paths within -2 km of the earth's surface. The aerosols are assumed to be horizontally homogeneous.

Falling snow is defined in XSCALE as precipitating snow carried by a wind of less than 5 m/s and a relative humidity of less than 95 percent. Crystals of falling snow are generally large in comparison to visible and IR wavelengths. The geometrical optics approximations are expected to be valid. Therefore, the extinction coefficient is equal to 2.0 and the resulting extinction is wavelength independent. However, field measurements of transmittance usually have exhibited a wavelength dependence in falling snow such that the extinction coefficient increases with wavelength in the absence of coexisting fog. This observed spectral dependence is explained for the most part by considering diffraction effects. Thus , as the wavelength increases, less diffracted energy is directed along the LOS to enter the transmissometer, resulting in an increasing extinction coefficient with wavelength.

2.4.4 Dust Model

The dust storm model has been constructed from extinction coefficients that were taken at the BCIS experiment at the Mounted Warfare Testbed, Ft. Knox.

2.5 Battlefield Obscurants

Obscuration of the battlefield from burning vehicle smoke, smoke signals, smoke pots, smoke generators, artillery dust and muzzle dust are provided by EOSAEL'S Combined Obscuration Model for Battlefield Induced Contaminants (COMBIC) (Hoock, et al, 1987). COMBIC models the production, transport, diffusion and non-uniform structure of battlefield obscurants. The model uses semi-empirical and first-principle physics to compute the influences of wind, humidity, temperature and pressure on the aerosol yield, cloud buoyancy, transport and diffusion. The design requirement was to predict transmission for any 3-D orientation of target and observer pairs, for (in principle) any number of battlefield obscurant sources produced at different coordinates and times. Values are computed for common spectral wave bands.

The primary input to COMBIC are environmental conditions (e.g., temperature, and wind velocity) and obscurant source conditions (e.g. , smoke munition type and burning vehicles). Each obscurant source is characterized by one to five subclouds, with each subcloud being either a Gaussian puff or a Gaussian plume. The model outputs a table of subcloud centerline trajectories, subcloud dimensions, the mean concentration downwind with respect to time, and the extinction. Collectively, this data is referred to as a COMBIC trajectory time history.

COMBIC calculations are performed in two phases. During Phase I, each type of obscurant source to be played is computed for one source and stored in look-up tables. These outputs are stored in a file. They include: the height of the centroid (puff) or height of the leading downwind edge of the cloud (plume); the x-y-z dimensions in Gaussian standard deviations; and the time required for the cloud to reach each downwind distance. They also include a time history of the cumulative amount of obscurant released for the total burn-time (emission time) of the obscurant. And, finally, they store certain individual values required for use in scaling the results to larger numbers or different sized fill-weights of obscurant. All meteorological conditions except horizontal wind direction are used in Phase I.

In Phase II, the user specifies LOS pairings and initiates obscurant source scenarios. COMBIC computes LOS geometries and intercepts, if any, with active clouds . For each intersection, it determines the amount of obscurant along the LOS by looking up the amount of obscurant that will have reached that LOS at that time for each source. This is multiplied by the extinction coefficients for each obscurant involved, and the total combined transmission through all relevant clouds and cloud types is computed for output at each wavelength band. Wind direction is the only meteorological condition allowed to be changed during Phase II, although vehicle directions are allowed to be changed during this phase. The final outputs are computed as the Beer-Lambert for transmittance.

Vehicular dust is a special case of battlefield obscurants. In this case, the source of the local obscuration is moving rather than stationary and the amount of obscurant is dependent upon the vehicle type (wheeled or tracked), vehicle weight, vehicle speed and the silt percentage in the soil.

2.6 Illumination and Signal Flares

Flares, launched via the ModSAF artillery editor, are modeled to burst, descend and extinguish. Upon receipt of a detonation Protocol Data Unit (PDU) for the flare munition, ModSAF looks up the configuration data for the flare and initiates simulation of the entity. The flare configuration data includes burst height, burn time, rate of fall, intensity and illumination cone angle. ModSAF calculates the movement of the flare (descent and travel with the wind) and issues environmental entity PDU's. Once the burn time has expired, the flare is marked “inactive,” with a corresponding change on the ModSAF plan view display in icon color from white to black. Eight seconds after the completion of the burn time, the flare entity is terminated.

Illumination flares are used to support target detection at night, and signal flares are used to trigger ModSAF phase changes in missions.

2.7 Weather-LINC (Live InterNet Connection).

As an adjunct to the Weather Editor the capability to connect ModSAF to live internet weather feeds has been implemented. A variety of Internet sites provide periodic updates, generally on the hour, containing surface weather observations. ModSAF can access a variety of sites by parsing the textual information provided by the Internet site and implements simple rules to instantiate quantitative values from the qualitative descriptions (e.g. , a reported observation of “light rain” is mapped to rain rate of 2 mm/hr).

ModSAF’s ability to consume publicly available weather observations from Internet sites provides an inexpensive and powerful tool for simulations playing in dynamic environments. The STOW program has demonstrated combined live and virtual weather simulations to illustrate the power of real-time weather information. These demonstrations utilize OpenScene visualizing a region in which the environmental conditions are provided via the ModSAF Weather LINC. As a correlation test, live Network Cameras (NetCams) are accessed via the World Wide Web displaying live out-the-window views of the same region visualized by the Stealth.

3.0 Conclusions

The DVW program is enriching the virtual battlefield with a range of real-world local and ambient environmental effects garnered from physically correct atmospheric models and real-world empirical values. The local effects modeled to date include obscuration due to high explosive artillery generated dust, smoke from burning tanks and other battlefield sources, vehicular dust, and signal and illumination flares. The ambient effects modeled include the variation of illumination with time-of-day, boundary layer aerosols, clouds, precipitation, snow and dust storms, ocean waves, and hydrologic effects on terrain. The incorporation of these and other real-world environmental effects is essential for distributed simulation applications ranging from training to test and evaluation.

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